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Doppler Radar for Heartbeat Rate and Heart Rate Variability Extraction

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Abstract—This paper presents a Doppler radar system used to detect the heartbeat signal from a distance of one meter. The proposed system is based on using a vector network analyzer and two antennas. Measurements are performed at 16 GHz for different power levels between 0 and -25 dBm. Both heartbeat rate and heart rate variability are extracted and compared to a simultaneous ECG signal.

Keywords: *microwave systems • Doppler effect • noncontact detection • cardiopulmonary activity • heartbeat rate*

I. INTRODUCTION

THE utility of microwave Doppler radar has increased for several applications. These include home health care applications, urgent conditions, and hospital needs. Affixed electrodes for traditional electrocardiograms are perturbing for long-duration home-monitoring, as well as for patients with conditions such as burn victims or newly born infants. In addition, a touch-less technique is necessary to detect life signs for people under rubble.

Based on the Doppler theory, a target with a quasi-periodic movement reflects the transmitted signal with its phase modulated by the time-varying position of the target [1]. When the target is the person's chest, the reflected signal contains information about the chest displacement, due to heartbeat and respiration. However, while holding breath, the reflected signal depends on the chest displacement due to heartbeat alone. At rest, the variation of the chest displacement, caused by respiration, is between 4 and 12 mm [2], and the chest displacement due to heartbeat alone ranges between 0.2 and 0.5 mm [3]. The respiration rate corresponds to a frequency that varies between 0.1 and 0.3 Hz, while the heartbeat rate (HR) corresponds to a frequency that varies between 1 and 3 Hz [4].

Previous works tend to detect life signs [5, 6], respiration rates and heartbeat rates, using fixed frequency and fixed power of the transmitted signal. Direct-conversion Doppler radars, operating at 1.6 GHz and 2.4 GHz, have been integrated in 0.25 μ m CMOS and BiCMOS technologies [7]. Heart and respiration activities were detected using a modified Wireless Local Area Network PCMCIA card, and a module combining the transmitted and reflected signals [8]. Other systems operating in the Ka-Band were described in [9, 10] using a low power double-sideband transmission

signal. Recently, a new study shows the possibility of detecting the presence of a person through a wall using Ultra-Wideband (UWB) radar [11]. Some experiments are performed for the detection of life signs using the 4–7 GHz band with 1 mW power and around 7 dB antenna gain [12]. Another system operating at 10 GHz showed the ability to detect the heart and the respiration activity of a person behind a wall [13].

In this paper, a microwave system for heartbeat detection is proposed and validated with an electrocardiogram (ECG) signal. In addition to the installation simplicity, the proposed system has the ability of tuning both frequency and power. As the transmission of a signal with minimum power would be safer for both the patient and the medical staff, the proposed system helps determining the optimal frequency with the minimum transmitted power before the implementation process. Both heartbeat rate and Heart Rate Variability (HRV) are extracted and compared to the values obtained by the ECG. The rest of the paper is organized as follows. Section II presents the proposed system and shows the heartbeat signal detected vs the ECG signal. Section III shows the heartbeat signals detected by the proposed system at 16 GHz for several transmitted powers. Section IV shows the results for the extraction of the heartbeat rate and the Heart Rate Variability (HRV) for both original and smoothed signals. Section V concludes the work.

II. PROPOSED SYSTEM

The proposed system is based on using a Vector Network Analyzer (VNA) (Agilent N5230A 4-Port) operating up to 20 GHz, and two horn antennas. Many features are available by using a VNA, such as the choice of the sweep time and the number of measurement points; therefore, the sampling rate. In addition, the frequency and the radiated power of the transmitted signal can be set and modified, and the time variation of the phase of the transmission coefficient S_{21} can be measured. Fig. 1 describes the proposed system.

More details describing this system can be found in [14-15]. The VNA generates a Continuous Wave (CW) signal at the desired frequency. The reflected signal off the person's chest is received by the antenna and fed back into the VNA, where the phase of S_{21} is computed.

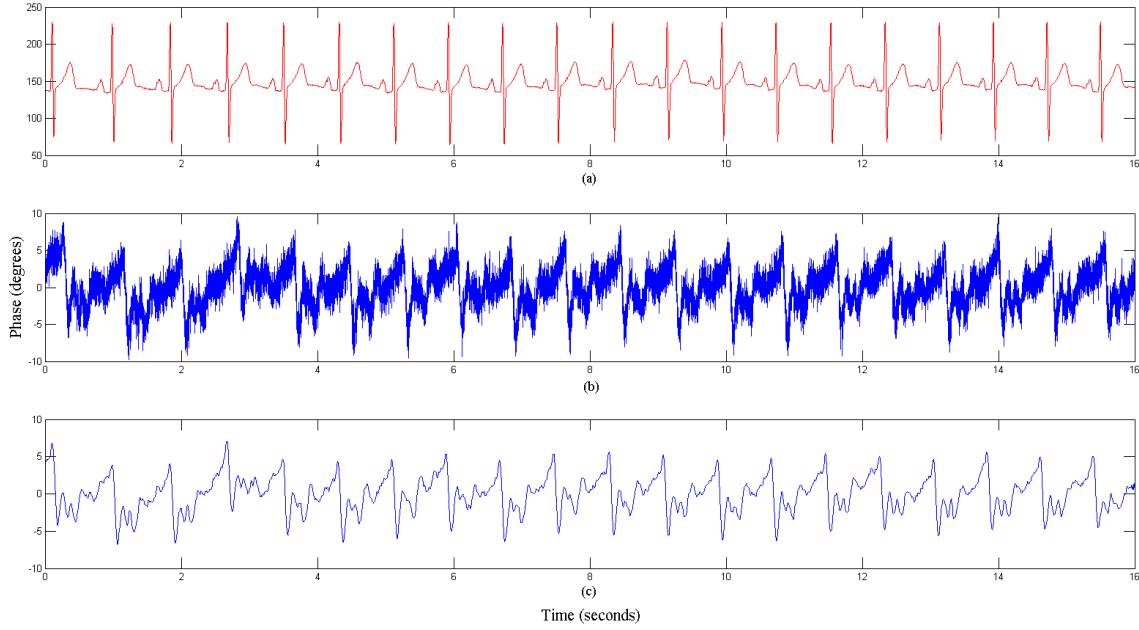


Fig. 2. ECG signal (a) and the phase variations due to heartbeats detected at 16 GHz and -5 dBm: original signal (b), smoothed signal (c)

This phase corresponds to the difference between the phases of the received and the transmitted signal. Measurements are performed at 16 GHz for several transmitted power: 0, -5, -10, -15, -20, and -25 dBm.

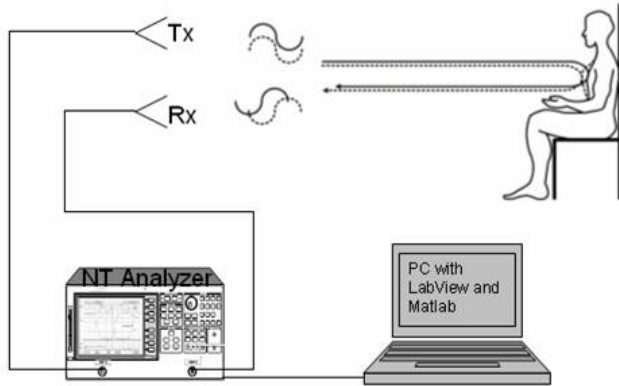


Fig. 1. Proposed system.

Fig. 2 (a) shows the heartbeat signal detected using an ECG, while Fig. 2 (b) shows the heartbeat signal detected using 16 GHz operational frequency and -5 dBm transmitted power. These two signals are obtained simultaneously for the same patient. Fig. 2 (c) shows the heartbeat signal after applying a smoothing technique. Beside that the heartbeat signal detected with an ECG represents the electrical activity of the heart, the goal of the

microwave Doppler system is to measure the heartbeat rate; this corresponds to the average of the R-R intervals.

III. HEARTBEAT ACTIVITY DETECTED AT DIFFERENT POWER LEVELS

One useful contribution of our work is to decrease the transmitted power. This would be safer for both patient and medical staff. A smoothing technique is used in order to improve the SNR of the detected signals. The smoothing method is based on the Newton relation:

$$(a+b)^n = \sum_{k=0}^n C_n^k a^{n-k} b^k$$

where $n+1$ ($n = 2m$ where m is a positive integer number) is the length of the smoothing window. In this case, the phase $p(i)$ is replaced by the weighted mean of the values: $p(i-m) \dots p(i+m)$. The weighting coefficients are given by the Newton binomial.

Fig. shows the heartbeat signal detected by our contactless microwave system at 16 GHz and for several transmitted powers: 0 dBm (a), -5 dBm (b), -10 dBm (c), -15 dBm (d), -20 dBm (e), and -25 dBm (f). It can be noticed that as the power decreases, the signal-to-noise ratio (SNR) decreases. However, the peaks of the signals can still be detected. The effects of smoothing these signals are shown in Fig. 4.

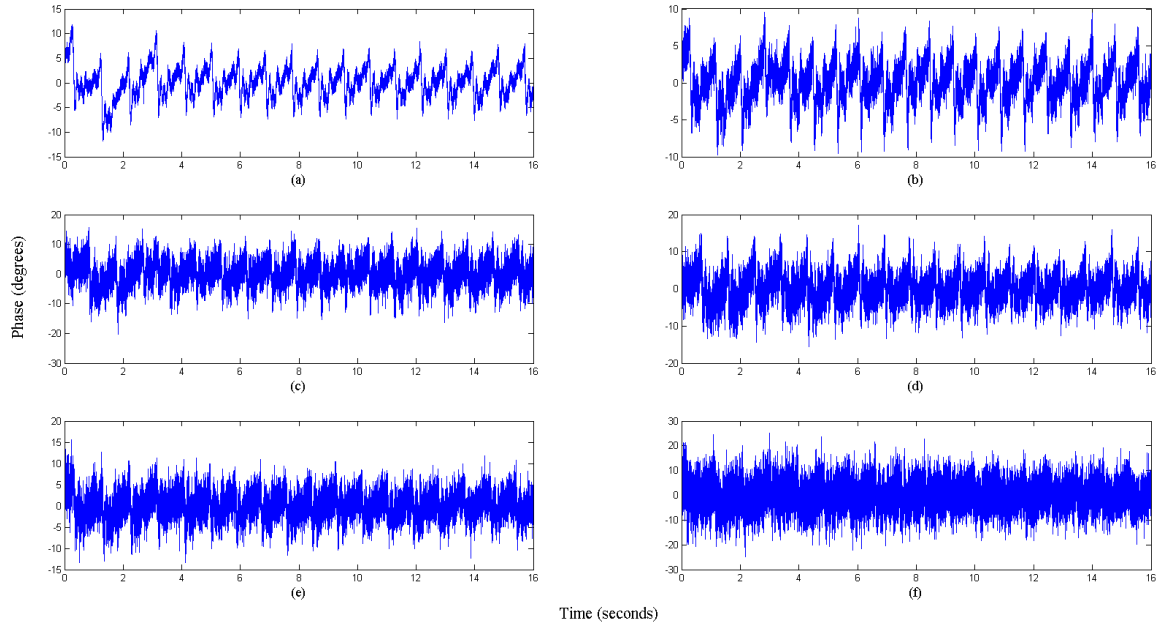


Fig. 3. Phase variations due to heartbeats detected at 16 GHz for the following transmitted power: 0 dBm (a), -5 dBm (b), -10 dBm (c), -15 dBm (d), -20 dBm (e), and -25 dBm (f)

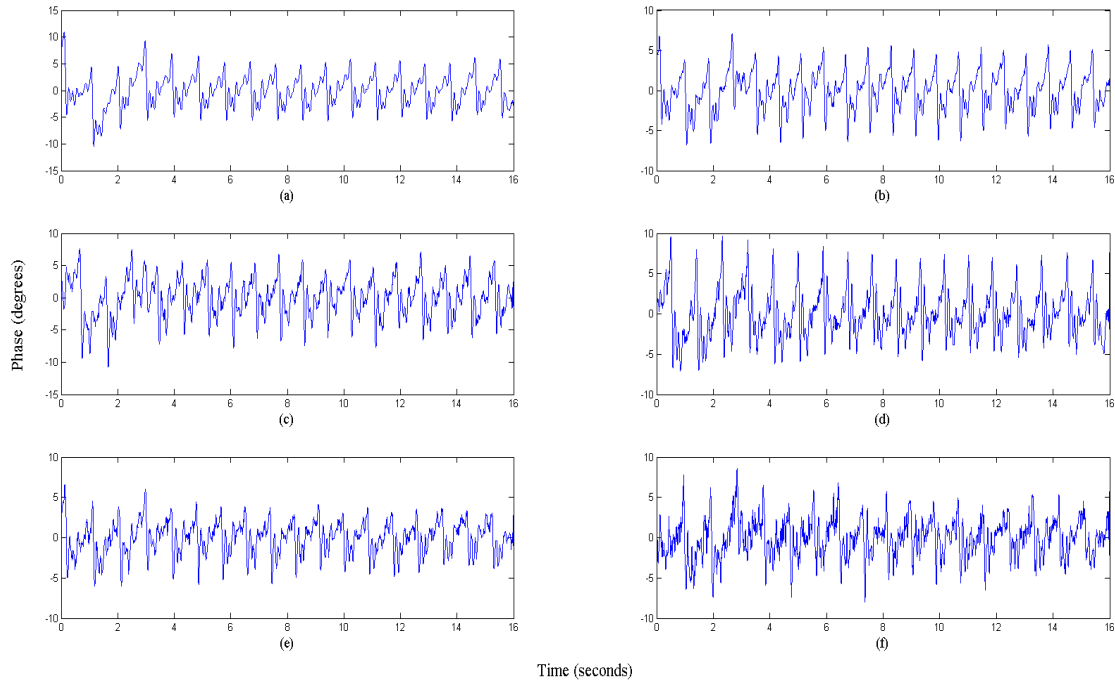


Fig. 4. Phase variations due to heartbeat signals detected at 16 GHz for different transmitted powers after applying the smoothing technique

IV. RESULTS: HEARTBEAT RATE AND HEART RATE VARIABILITY

Related works tend to extract the average heartbeat rate for a specific window. This does not provide information about the variation of the HR in time, *i.e.* the HRV. Thus, a peak detection technique is required to track the peaks of the signal. In this work, both the heartbeat rate and the HRV of

the signals detected at 16 GHz for different power levels are extracted. These values, for both original and smoothed signals, are compared to HR and the HRV obtained from the ECG reference signals.

Fig. 5 presents the relative errors of the heartbeat rate for both original and smoothed signals compared to the reference ECG signal.

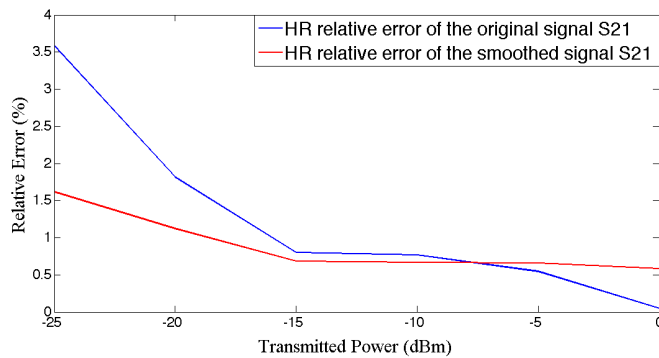


Fig. 5. Relative error of the HR: original and smoothed signals vs ECG

For different transmitted power values between 0 and -25 dBm (with a down step of 5 dB), the proposed system shows the possibility of detecting the heartbeat signal with a relative HR error between 0 and 3.5%. Smoothing the signals gives a relative error less than 1.5% for low power levels less than -15 dBm).

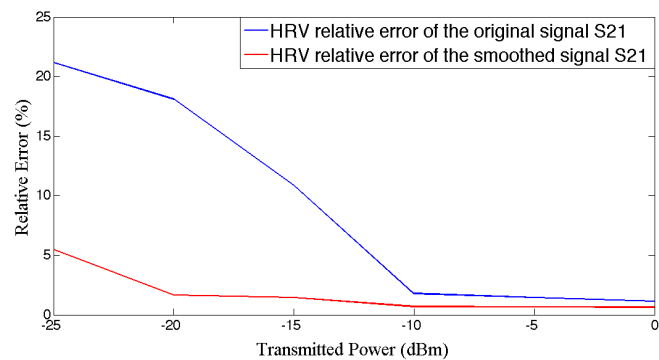


Fig. 6. Relative error of the HRV: original and smoothed signals vs ECG signal

On the other hand, as shown in Fig. 6, the relative HRV error varies between 2% and 21% while smoothing the signals improves this relative error to be between 1% and 6%.

V. CONCLUSION AND PROSPECTIVES

The proposed system shows the possibility to detect the heartbeat activity at 16 GHz for different power levels. The Doppler radar system is tested and compared to simultaneous electrocardiogram. The heartbeat activity is detected for transmitted power between 0 and -25 dBm and for a distance of 1 m between the person and the antennas. Both heartbeat rate and heart rate variability are extracted from the proposed system and compared to the reference signal. A high accuracy is observed for the average HR: its relative error varies between 0 and 3.5%, while it varies between 2% and 21% for HRV. A smoothing technique is applied as well to the original signals in order to improve the detection accuracy. The relative errors decrease to 0.5 – 1.5% for the HR, and to 1 – 6% for the HRV.

Our future work will focus on measuring the heartbeat activity for different operational frequencies and different transmitted power levels.

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